# Literature Survey on Scheduling and Resource Allocation for IEEE 802.11ax

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## 1 Introduction

IEEE 8021.11 is the standard defined for WLAN(Wireless Local Area Network). It first came into the picture in 1997 which offer a speed of 2Mbit/s. After that we have different versions, 802.11b having speed 11Mbit/s, 802.11a/g having 54 Mbit/s, 802.11n having 600 Mbit/s, and even above Gbit/s rates in the latest 802.11ac. These speeds can be achieved by means of different modulation and coding scheme, wider channel and adaptation of Multiple Input Multiple Output (MIMO) technologies[7]. The 802.11ax will provide outstanding average throughput in the dense environment. Many clients connect with the Access Point (AP) simultaneously using the Orthogonal frequency-division multiple access (OFDMA) where AP divides the entire frequency band into multiple subsets of orthogonal sub carrier called as Resource Unit (RU),These RUs are assigned to different user to transit in parallel which make 802.11ax different from all other versions of 802.11 so we need some scheduling and resource allocation mechanism to utilize the features of 802.11ax. Before going to scheduling and resource allocation, let us discuss some features of 802.11ax.

The key feature is the adoption of OFDMA approach that better utilizes the wider channels 80Mhz,80+80 Mhz and 160Mhz. The 802.11ax amendment comes with a new modulation technique which is 1024 QAM which can achieve speed up to 9.6Gbps. Apart from this, it also describes an optional Dual Carrier Modulation(DCM). There is also a change in the PHY Frame Format. Along with the legacy part of the preamble, it also contains HE(High Efficiency) as a part of the preamble. The HE-STF and HE-LTF fields are used for Multiple-In Multiple-Out (MIMO).In 802.11ax networks, the AP not only selects an appropriate rate for its own transmission, but also for the UL MU transmission. For that, it collects reports on signal strength from associated devices prior to allocating UL channel time to them [7]. The 20 MHz band corresponds to a 242-tone RU, 40 MHz band corresponds to a 484-tone RU, 80 MHz band, and 80+80 (160) MHz band corresponds to a 996-tone RU and two 996-tone RU respectively. For the uplink multi-user OFDMA transmission the AP will transmit a special triggered frame that indicates that clients send the data packet and after receiving the AP reply with Acknowledgment frame.STAs(Stations) uses OFDMA Back-off (OBO) procedure to decide whether to transmit or not.Each STAs chooses a random value from 0 to OCW where OCW is OFDMA contention window As

described by [7] If the transmission attempt fails, the STA doubles its OCW until it reaches OCWMAX and selects an OBO value from the new interval. If the transmission attempt is successful, the STA resets its OCW to the minimum value OCWMIN, From the above point is clear that random access is less efficient than schedule access and thats why we need a scheduling algorithm.To overcome the problem of Overlapping in dense environment 802.11ax uses BSS coloring which is a transmitted in the frame preamble, Two NAVS, Quiet Time Period,Adjustment of Sensitivity Threshold and Transmit Power. 802.11ax also provide better power management, AP uses Traffic Indication Map (TIM) in beacons to tell the STAs about the frames.It also adopted TWT from 802.11ah and microsleep approach from 802.11ac. From all the above features, most interesting and challenging is the adaptation of OFDMA in Downlink and Uplink, which allow different clients to transmit data concurrently and hence we required better scheduling and resource allocation to increase the aggregate throughput in the dense environment.

# 2 Literature Review

In [6] author discuss about the energy efficiency of 802.11ax dense network after 2018 the Wifi traffic took edge over the wired one. We have to provide the quality of service in the dense environment. To improve energy efficiency, we have different options like improving hardware, better network planning and resource allocation. They proposed an algorithm for better energy efficiency, first they analyse the utility function and come up with the new objective function and then provide the static solution of the optimize problem and lastly with dynamic scheduling as in dense network there may be some clients which have low transmit power so they can not be transmitted simultaneously. Lastly they compare the result with the legacy Wifi, scheduling, power control scheduling, and energy-efficient power control scheduling. For the case of scheduling, they find the increase of throughput. Also find that energy-efficient power control allows substantially decreasing energy consumption having the same throughput. In future work, they are proposing an algorithm for dynamically changing the environment.
In [2] author used BSR (Buffer State Report ) based two-stage mechanism for adaptive grouping scheme in ultra dense IEEE 802.11ax Network. Buffer Status Reports (BSRs) help the AP to schedule the transmission in allocating UL MU resources. STAs also send their BSRs to AP to know about their Queue size, quality of service labels. The mechanism is very simple where AP broadcast the triggered frame for BSR polling (BSRP-TF) and STAs receive these frame and send the data and AP response with Multi Block Ack. While in Buffer status report based two-stage mechanism (BTM) where in stage one BSR is used to solicit the necessary information for scheduling. And after that in stage two, the AP allocates the different resources to different STAs and STAs transmit their data frame only on those resource units. Authors proposed a novel two-stage based BSR mechanism where AP divides the STAs into groups based on their TWT(Target Wakeup Time), when one group is sending data, other groups go into doze state to avoid the collision. The results show that the proposed grouping scheme helps to reduce the high collision rate and maintain a good performance in ultra-dense networks. Also, author [2] concluded that having different group sizes enhanced AP's capability to address the resource allocation problem.In [8] authors discuss about the IEEE 802.11ax MAC layer and suggested that the feasible solution to avoid collision is by using a centralized mechanism where AP get access to the chan-

nel and allocate the resource to the STAs and having a better scheduling algorithm they proposed a DISTRIBUTED CONTENTION RESOLUTION ALGORITHM and provide an algorithm for STAs and AP both. On Client side the contention window is initialized and for every triggered frame, the OBO is reached zero we assigned a RU. This scheme provides fairness to the channel. The Clients and AP both have fair access to the channel. The centralization system of AP is best to avoid collision only when there is fairness in the channel. The result obtained from the proposed scheme is much better than the existing solution. Future work may include investing in providing QOS , cross layer optimization MAC and PHY layer.
In [4] [3] [5]author talks about the Resource Management and Scheduling n the Uplink Transmission in 802.11ax network.The AP has the knowledge of each packet of the STAs and hence it can schedule and allocate the Resource Unit. In Uplink, AP can allocate the RU in two manners one with Schedule based where contention-free transmission is possible, and other is Random Allocation of RUs. AP gets to know the BSR (Buffer Status Report) of the STAs via Random access. In [4] they proposed an optimal Resource Allocation scheme where optimal means getting a balance between Schedule Resource allocation(NSA) and Random Resource Allocation(NRA). The algorithm is as, First AP gets the BSR(Buffer Status Report) and sort it in non-increasing order. After that, select the STAs which have the largest BSR an allocate the schedule RU to that station and reduce the number of Resource unit. Similarly do for others and left will be allocated as Random Access Resource Unit. In the proposed algorithm, AP updates the BSR (Buffer Status Report) for each triggered frame. They validate their algorithm by implementing it on the NS-3 simulator. After extensive simulation, they conclude that larger throughput can be achieved in uplink multi-user OFDMA transmission when the ratio of the number of schedule and Random Access RUs is equal to one. they also perform their simulation for combined uplink and downlink traffic.In [5] also describe about Resource management in OFDMA based transmission. The adaptation of OFDMA in WIFI 6 help to improve the performance in dense network. The author proposed two algorithm one where the scheduling duration is fixed and other where scheduling duration changed based on the queue size and channel condition. They proposed a new protocol named Dynamic PPDU (D-PPDU). Here the AP first send the Triggered frame whcih indicate the IDs of the group which is going to be schedule after receiving the triggered frame, the STAs send their BSR(Buffer Status Report) and based on that AP estimates the uplink transmission rate After optimizing the scheduling duration AP sends optimal scheduling duration within Optimal Tme Frame. we can maximize the optimal scheduling duration to increase the throughput. There may be overhead in the D-PPDU however, it can be minimized .The optimization problem can be easily formulated with Lyapunov optimization technique. They said that we can use other scheduling algorithms like Randomized and Dynamic Programming techniques to develop better scheduling and Resource Allocation in the future. In [3] authors explains how the resource units are distributed in 802.11ax as RUs consists of 23,52,106,242,484,996 and 2*996 OFDMA tones.The set of RUs depends upon the channel for e.g the 40Mhz channel can use upto 484 RUs. They develop a novel scheduler called MUTAX, acronym is Minimizing Upload Time in 11AX Network.The algorithm divides the channel into several RUs and for possible set of RUs, they find the total transmission time and trying to minimize the total transmission time. They evaluate their result on NS-3 simulator. Apart from MUTAX algorithm, they also implement some famous scheduling algorithm like Max

Rate(MR), Proportional Fair(PR) and Shortest Remaining Time First (SRTF). The result for MUTAX is quite good.In future they are planning to come up with more restricted based scheduler based on the standard of 802.11ax.
In [1] author discussed about the resource allocation for Real-Time Application in IEEE 802.11ax network. They proposed an algorithm that decreases the real delays for real-time traffic. Above, we discussed how the Uplink transmission work in 802.11ax OFDMA. They called the Resource Allocation algorithm as Cyclic Resource Allocation Algorithm. The aim of this algorithm is to minimize the RTA ( Real-Time Application) data transmission delay. It starts scheduling at the starting of the slot and allocates only the smallest RUs i.e. 26 tone RU to the RTA. The main aim of AP is to allocate the maximum number of RUs such that the maximum number of STAs can transmit simultaneously. Let us consider we have a total N number of RUs out of which n are assigned as Random access and rest as schedule. The numerical result shows that the average delay is less than 1ms, which is good and well established for Real-Time Applications. The algorithm is efficient in delays and also in a channel resource allocation for RTA ( Real-Time Application).In [9], authors talks about the Quality of Experience in Wireless Network, especially for the video streaming. They proposed a QoE- aware scheduling for video streaming for IEEE 802.11n/ac. The scheduling is quite simple, which is trying to prioritize the queueing packet. Author discussed different type of scheduling methods which prioritize the packet like Early deadline First (EDF), Modified Largest Weighted Delay First (M-LWDF).In the other proposed algorithm, they calculate the delay of the transmission of packets if the delay is greater than 100ms, then they drop the packet because greater than 100ms transmission time will not provide quality of experience for video streaming. And if the transmission of paket can be achieved in less than 100ms then we can schedule with maximizing the sum rate. The result shows that the QoE scheduling scheme is quite good. It enhances the video quality by only considering the HOL(Head of Line) information. They also defined a delay utility function based on channel link that maintains the fairness in the channel.One of the optimal scheduling and resource allocation in IEEE802.11ax is discussed by [10]. They come up with the novel divide and conquer algorithm which is optimal.They can partition the resource unit into several levels and allocate the resources recursively. For each resource, they try to maximize the Sum rate. The novelty in their algorithm lies in the fact that how they divide the Resource unit. They proposed two algorithms one is greedy find the group which have maximum sum rate and allocates the resource to that group and the other is Recursive Scheduling, where each RUs is divided into multiple RUs.The simulation result shows that result obtained from the Recursive Scheduling is closed to optimal.

# 3 Summary

The new standard of WiFi aim to provide best aggregate throughput in dense environment, which can be achieved easily if the transmission happens without collision. The AP gets centralized access to the channel. In 802.11ax, the adaption of OFDMA allows the STAs to transmit the packets simultaneously. So we need scheduling and resource allocation scheme to utilize the feature better.As we discussed above different algorithms. There is still a need for a much better algorithm. There are many popular algorithms like Max Rate (MR), Proportional Fair(PF), Round Robin (RR), Earliest Deadline First(EDF), Largest

Weighted Delay First (LWDF), and many more. From all the above Literature surveys, we conclude that there is a large number of research areas open for optimal resource allocation and scheduling in IEEE 802.11ax. Some of the authors use BSR(Buffer Status Report ) for uplink OFDMA transmission, while others are trying to optimally divide the resource into random access and schedule access. Many works on OFDMA contention window to provide fairness into the channel among the legacies devices. The things we might get from this literature survey is that we can easily increase the average throughput of dense Wifi Network in IEEE 802.11ax. we can even achieve a maximum speed of 9.6Gbps.

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